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THE APPLICATION OF SPACE PROGRAM FIRE-RETARDANT TECHNOLOGY TO HOUSING

by S. R. Riccitiello and K. W. Heising

Ames Research Center
Moffett Field, Calif. 94035

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A review of the NASA fire research and developed fire retardant materials is presented. The objective of the review was to analyze and evaluate the concepts and materials to determine the practical applicability to the housing industry. The report presents the NASA materials, their performance in a fire environment and areas where further evaluation is required. The review establishes where advancements in the state of the art have been achieved and points out reasons why these advancements can not be directly applied to the housing industry in the near future.

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S. R. Riccitiello and K. W. Heising[1]

Ames Research Center

SUMMARY

A review of the NASA fire research and developed fire retardant materials is presented. The report presents the NASA materials, their performance in a fire environment and areas where further evaluation is required. The review establishes where advancements in the state of the art have been achieved and points out reasons why these advancements can not be directly applied to the housing industry in the near future.

INTRODUCTION

The U. S. Department of Housing and Urban Development (HUD) has indicated an interest in the fire-retardant technology developed for the aerospace program. Following discussions between Ames and HUD personnel, an informal study was initiated to analyze and evaluate work done by NASA and NASA contractors on applications of plastics (polymer) technology to the retardation of fire and smoke in structures. The study objective was to determine the practical applicability of this technology to housing.

BACKGROUND

Fire has been defined as a combustion process accompanied by heat and light. Emmons describes a fire as having five phases[2] (1) initial, (2) growth, (3) steady state, (4) decay, and (5) cool off. Ignition occurs during the initial phase, and requires four conditions: temperature, an oxidizing agent, a reducing agent, and an uninhibited chain reaction. During the initial phase, the important considerations, regardless of the material, are the ease of ignition, the amount of material present, and the extent of exposure. The severity of a fire varies with the type and amount of fuel available to burn. Table 1 gives the equivalent fire severity for dwellings as a function of combustible loadings (ref. 1). Note that this severity rating considers fuel loading only and is intended merely as a guide to show the potential energy of cellulosic materials if and when combustion occurs.

It should be noted that fire resistance as a mandatory requirement for dwellings has not been given adequate emphasis. Fire and the accompanying phenomena progress to become a threat to human safety with frightening speed. The time it takes a fire to render an area incapable to support

[1] Headquarters, NASA

[2] Lectures by Prof. H. Emmons, Division of Engineering & Applied Physics, Harvard University.

TABLE 1

Average weight of combustibles, lb/sq ft (4.88 mg/m^2)	Equivalent fire severity, hr
5	1/2
7-1/2	3/4
10	1
15	1-1/2
20	3
50	6

life is of the order of five to ten minutes – less than the response time of the best trained, fortuitously located fire department. In buildings that do not have automatic fire extinguishing equipment (sprinklers operated by fire detectors), which is true of almost all private dwellings, the only recourse is evacuation of individuals from the fire area.

POLYMERS AS BUILDING MATERIALS

Polymers are organic, and their use as building materials therefore has a number of significant disadvantages:

1. In general polymers are more expensive than conventional building materials.

2. Many conventional polymers are flammable.

3. Polymers lose strength when exposed to mild heating and can spread a fire if they flow or drip.

4. Polymers have a higher potential thermal-energy fuel content by weight (greater than 8000 Btu/lb (2.3×10^4 J/kg)) than in cellulosic materials.

In spite of these disadvantages, which have been well known for a number of years, the use of polymers in the construction of dwellings and furnishings has increased dramatically, although they still account for a small fraction of the approximate $50 billion current annual market for construction materials and supplies. In particular, polymers are being used increasingly for drain, waste, and vent pipe applications (DWV). Approximately one-third of the single-family homes constructed in 1972 were equipped with DWV plastic pipe. The use of polymer siding is also on the increase, but this material has attained less than 5 percent of its potential market. Urethane foams are used as dwelling insulation, but the fire-retardant properties of these materials are poor, and the foams must be shielded from any potential fire conditions.

There are a number of good reasons for the increasing use of polymers despite the problems outlined earlier. There is a pressing need in the United States for good low-cost buildings, and polymers offer some promising long-range solutions. Factory-constructed housing is a potential means of offsetting, at least in part, spiraling labor costs, and polymers are more suitable than most classes of materials to mass production techniques (ref. 2).

The real advantages of polymers as a primary construction material have not begun to be exploited. The problem of higher cost for many applications is certain to be solved with increased use and demand. The task of improving the fire resistance of polymers will increase costs initially and will probably delay the time when polymers are accepted as a primary class of materials in the building construction industry.

NASA FIRE PROGRAM

NASA's fire program emphasizes the prevention of ignition itself by attempting to eliminate the prerequisite conditions for ignition to occur, or failing that, extinguishing the fire as soon after ignition as possible (refs. 3 - 9).[3] Thus, the primary NASA concern was fire prevention, without the consideration of smoke and toxic gas hazards. An experiment included in the NASA aeronautics program was designed to establish the feasibility of protecting the passenger cabin of an aircraft from external fuel fires; this work is covered in a later section (ref. 10).

As noted earlier, one of the prerequisites for ignition is an uninhibited chain reaction (ref. 5). The use of halogens as inhibitors of chain reactions has been studied by NASA for several years (refs. 11 - 12).[4] The halogen may be present in the molecular structure of the polymer or added as an organic halide or a halide-containing salt. These NASA studies have to the use of a number of halogenated base (fluorinated hydrocarbons, Fluorel, Viton) compounds which retard fire propagation and thereby reduce the combustibility of materials that otherwise would be flammable (ref. 9).[4]

While these polymers have the desired effect of inhibiting combustion, polymer degradation and oxidation can yield toxic pyrolysis products at elevated temperatures. This property has significant implications in the nonaerospace fires where one might escape the fatal consequences of the thermal effects of a fire but must endure exposure to products of combustion and thermal decomposition. NASA is investigating a method to determine the toxic properties of pyrolysis by-products of materials via the variance of impulse transmissions in a frog heart vagus nerve (refs. 13 - 18).

The critical processes in combustion, polymer degradation, and flame suppression are under investigation to provide a basis for modifying the polymer structure to prevent ignition (refs. 19, 20).[5] In polymer flammability, work is being devoted to the oxidative and degradation processes occurring close to and in the solid phase of polymers (ref. 20). In these studies, electron spin resonance and mass spectrometric methods are being used to determine the onset of polymer degradation and the oxidation resistance of high temperature polymers. In the area of flame suppression, basic suppression mechanisms are being investigated in hydrocarbon and hydrogen fueled flames.

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[3] Lecture by M. I. Radnofsky and E. W. Gauldin, Manned Spacecraft Center, NASA, 1971.

[4] Paper "Flame Inhibition by Hydrogen Halides – Some Spectroscopic Measurements," by N. R. Lerner and D. E. Cagliostro, submitted to J. of Combustion and Flame, 1973.

[5] "Study of Aircraft Fire Safety: Flame Spreading Across Material," by I. Glassman and W. A. Luciano. Princeton Univ., Contract NAS2-6705.

NASA MATERIALS DEVELOPMENT PROGRAM

Using results of the fire program as a guide, NASA initiated a materials development program, which included materials developed by contractors and by NASA. Some of these are outlined below.

Materials Developed by Contractors

1. An extremely fine diameter, inorganic (nonburning) glass fiber called Beta was developed with improved abrasion resistance as compared to existing fiberglass fibers (refs. 4, 8).

2. Flame resistant polybenzimidazole fiber, whose development was initiated by the U. S. Air Force, is now being fabricated into a cloth for fire suit application (refs. 4, 21).

3. A recently developed phenolic fiber, Kynol, retains its identity when exposed to flame temperatures up to 1350° C. This fiber was originally used for belts and battings, but with improved spinnability, conventional knitted and woven fabrics are now available. Suits made from these fabrics have been demonstrated to be highly effective protective outer garments for firemen and race drivers (ref. 9).

4. Teflon fiber made from a fluorocarbon polymer burns slowly in pure oxygen, and has excellent chemical resistance, good wearability, and a low friction coefficient. Some Apollo intravehicular flight coveralls were fabricated from bleached-white teflon fabric (refs. 4, 9).

5. A fire retardant wool treated with a chemical process called Proban was developed. This material does not burn in air and is available in a wide range of colors (see footnote 2).

6. A similar process called THPC is used to impart fire retardant qualities to cotton and cotton-based fabrics (ref. 9).

7. Elastomeric fluorocarbons, basically copolymers of hexafluoropropene and vinylidene fluoride, have been synthesized. Among the available elastomers are Fluorel developed by Minnesota Mining and Manufacturing Company, marketed by Mosites Rubber Company and Raybestos-Manhattan Incorporated, and Viton developed by E. I. DuPont. Compounded fluorocarbon elastomer can be foamed, cast, molded, or extruded. The material also can be applied as a paste, coating, or a spray solution (refs. 4, 9).

8. An asbestos foam has been developed by the Rex Asbestos Works of Germany. This material is marketed in batting and sheets and should be useful for general insulation applications (refs. 4, 9).

9. Scott Paper Company has developed Pyrelle foam, an inexpensive, commercially available polyurethane with a good weight-to-thickness ratio. Their "Super-Pyrelle" is a version with improved flammable properties, which retains good physical characteristics (see footnote 2).

10. Laminite Corporation has developed a nonflammable corrugated board panel. This concept has been demonstrated, and current work is directed toward improving the physical characteristics including weight reduction (see footnote 2).

Materials Developed by NASA

The work at Ames Research Center on fire protection and fire suppression originated in 1967 with the development of heat shield materials and thermal-protection coatings for spacecraft. This work led to the development of the following classes of fire-retardant materials in the forms of lightweight polymeric foams and intumescent coatings.

1. NASA modified urethane foam is a composite foam containing a halogenated polymer, polyvinylchloride, which increases the foam char yield and released HCl gas to aid in fire suppression. An inorganic salt, potassium fluoroborate, aids in fire suppression and provides char stability. A microencapsulated volatile halogen-bearing compound is added to the foam to reduce material flame spread. Fibers may also be incorporated in the foam where high mechanical strength is required (refs. 22, 27).

2. NASA polyisocyanurate rigid foam was developed to provide improved thermal performance at a minimum weight as compared to the polyurethane foam, while maintaining mechanical properties equivalent to a polyurethane foam. Tests have demonstrated that the polyisocyanurate foam maintains better dimensional stability than the modified polyurethane foam with an improvement in char yield at 538° C (ref. 23).

3. A "nonburning" flexible foam system was developed by adding polyvinylidene chloride to a neoprene-isocyanate foam and post curing. A flexible foam fire blanket using the neoprene-isocyanate flexible foam between two sheets of asbestos was developed as a fire protection wrap system for field application (ref. 23).[6]

4. NASA has developed a new class of intumescent coatings. The intumescent process, the swelling of a material forming a low density foam with the application of heat, has been used for many years in the form of surface coatings to offer protection of fire-sensitive building materials. The major disadvantage of the state-of-the-art intumescent coatings that exposure to humidity renders them ineffective (refs. 24 - 26).

The advent of new high-temperature and oxidation resistant heterocyclic polymers such as the polythiazoles, polyphenoxazines and polyquinoxalines raised the possibility of developing new kinds of intumescent materials if a method could be found by which these polymers could be made in place.

NASA's approach to the development of an intumescent material was to select suitable monomers or prepolymers that would react when exposed to heat to give thermally and oxidatively suitable aromatic heterocyclic polymers. During the polymerization process, the evolution of by-products from the condensation polymerization acts as a blowing agent to form the intumescent low density foam material. The polymerization also must proceed through a molten phase to ensure the desired degree of plasticity during expansion. Finally, to ensure a mechanically coherent foam structure that will not collapse, a high degree of polymerization must be obtained by the time the expansion is completed.

NASA conducted a study where a number of various substituted nitroaromatic amines were examined for intumescent properties. Expanded black polymers were formed from both

[6] Material and Process specification supplied upon request from NASA Ames Research Center.

o-nitroaniline and p-nitroaniline, as well as from their substituted derivatives, when heated in the presence of a strong mineral acid. These materials have excellent expansion of 70 to 240 times the original volume when heated to a temperature of 199° to 260° C. The observation of the effect of heat and acid on p-nitroaniline led quickly to the development of the associated bisulfate salt as a dry compound and as an intumescent agent. Two coatings were developed using the p-nitroaniline bi-sulfate salt as the intumescent agent. These coatings performed satisfactorily, although they too had the environmental or weathering limitation (ref. 24).

Additional studies revealed that the sulfonic acid salt of p-nitroaniline also intumesced and was not affected by high humidity conditions. An intumescent coating, 45B3, was formulated with the ammonium salt of p-nitroaniline-o-sulfonic acid dispersed in a binder composed of equal parts of a polysulfide and an epoxy polymer. The coating provides a hard, glossy, abrasion-resistant surface. Exposure of the coating to 37.7° C temperature and 90 percent relative humidity for 30 days resulted in no significant change in the thermal performance of the coating. Exposure of the coating to the local northern California elements for one year did not deteriorate the effectiveness of the coating (refs. 28, 29).

MATERIAL EVALUATION

As noted, polymers contain an organic substance of large molecular weight, and therefore are combustible when exposed to sufficient heat and oxygen. When the material reaches its decomposition temperature a number of combustible and noncombustible gases may be liberated as well as polymer fragments, which appear as smoke. The amounts and manner in which these by-products of decomposition appear define the fire hazard. The release of combustible gases will support combustion and, of course, spread the fire. These gases, and the noncombustible ones as well, may be irritating or toxic and might also accelerate the destruction of the material by altering its physical and chemical structure. The altering of the dimensional stability of the polymer through conversion of the polymer to liquid might also spread the fire. The formation of solid char during decomposition seems to restrict the spread of fire and hence is an index of fire resistance (refs. 30 - 33).

ASTM has developed a series of test procedures for defining the fire properties of materials. Most local building codes have adopted these standards to screen various materials prior to use. Except in specialized cases, the aerospace materials have to be evaluated in accepted ASTM test procedures before they can be applied. To date, only a few of the contractor developed materials and none of the NASA developed materials have been evaluated under ASTM procedures. The various materials tests are as follows:

Ignition Tests

1. ASTM D 635
2. ASTM Test EL-36-65
3. ASTM 737
4. ASTM 1692

Surface Flammability Tests

1. Steiner Tunnel Test ASTM E-84
2. Robertson Radiant Panel Test ASTM E-162

Endurance Test

1. ASTM E-119

Heat Contribution Tests

1. ASTM E-84
2. ASTM E-162

Smoke Production Test

The most popular test is the smoke test developed by the National Bureau of Standards. The test employs a closed cabinet having a volume of 18 cubic feet. A 3-in.-square test specimen is exposed to heat under either flaming or nonflaming conditions. The heat source is adjusted to give heat flux of 2.5 W/cm^2 at the specimen surface. Light absorption by a photometer is measured vertically to minimize differences caused by stratification of the smoke. Smoke measurements are expressed in terms of specific optical density. The test provides additional information, such as maximum smoke accumulation, maximum smoke accumulation rate, and time to reach maximum smoke density (ref. 34).

Toxic Gas Hazard

There are few code regulations today covering toxic gases, and knowledge of the subject among fire fighters is fairly limited. The increased use of polymeric materials could increase the hazard and necessitates that toxicity be taken into consideration systematically along with the other hazards associated with a fire.

Scaling Test

Some work has been done to test the ability of small scale tests to predict smoke production of interior finish materials in large fires. Such tests were conducted by the IIT Research Institute for the Society of the Plastics Industry (ref. 35). Full-scale test results were provided by various organizations. The data on smoke production indicate that the smoke hazards of interior finish materials are not adquately defined by a smoke rating number from a single small scale test. The inadequacies of the test seemed to result from an inability to produce the extremely heavy smoke associated with total involvement of some of the high fuel content samples. Improved methods must be devised to predict smoke production.

The IITRI plastics tests for comparing smoke production measured on a small scale with that of full scale fires also provided comparison data on flame spread and heat production measurements obtained with the 25-foot (7.6 m) tunnel with those of scaled fires. In the full scale fires, materials location and magnitude of fire exposure both had a pronounced effect on material behavior. In general, however, the patterns obtained indicated that the materials have the same relative hazard

position on each curve. The 25-ft (7.6 m) tunnel E-84 flame spread number does not quite place them in what appears to be the proper order. It also does not appear practical to distinguish between the hazards of materials whose flame spread numbers differ by 25 or less (refs. 36 - 41).

APPLICATION OF NASA'S FIRE-RETARDANT CONCEPT TO AERONAUTICS

The importance of the proper utilization of fire research and technology in solving a practical problem can be illustrated by NASA's experimental work on the protection of aircraft structures from external fuel fires (ref. 10).

A continuing hazard to aviation is the aircraft ground accident that does not result in massive fuselage damage but does involve an external fire caused by fuel spillage. Passengers, even though only slightly injured, are subjected to a massive heat and fire environment within seconds after a fire starts. This was the case in an aircraft crash several years ago at Salt Lake City, Utah. Earlier attempts to minimize this hazard have stressed rapid evacuation techniques or actual fire prevention or control. The program at NASA/Ames, on the other hand, was based on the concept of building the passenger compartment with a fire-protection shell that would protect the occupants long enough for the fire to burn out or for fire-fighting equipment to reach the airplane and extinguish the fire.

The feasibility of this concept depended on the advent of two new fire-protection materials developed by NASA: lightweight foam and an intumescent coating. The thermal protection mechanisms of these materials operate on the same principles as those used to protect the astronauts during atmosphere re-entry. To demonstrate the material use in a full-scale application, an aircraft fuselage was fitted with the materials and tested in a jet-fuel fire. The details of the fire protection system for the aircraft section are shown in figures 1 and 2.

The fuselage was placed directly on the ground and was flanked by two shallow pits (30 X 50 ft (9.15 m X 15.25 m)). Water was placed in the bottom of the pits and 2,500 gal (11.37 m^3) of JP-4 fuel was floated on the water. The fuel in both pits was ignited simultaneously. The quantity of fuel was estimated to produce a fire that would envelop the fuselage for a period of ten minutes.

The test was severe, but representative of the conditions of a ground crash fire with an intact fuselage. Figure 3 shows the fire at its maximum development. The results of the tests are illustrated in figure 4. The unprotected section was destroyed within two minutes, but the protected section remained intact throughout the fire which lasted for 12 min. The inside cabin reached a maximum temperature of 150° C as the fire burned out. A rapid rise in temperature occurred after this period as a result of a structural failure at the bottom support area of the fuselage. This provided a path of heat penetration. The test results were encouraging and further work is being considered to develop a thermal protection system applicable to commercial aircraft.

APPLICATION TO DWELLINGS

The aircraft fire problem is not unlike that encountered in housing or high-rise building fires. The control of the fire to prevent spreading, and the evacuation of individuals to prevent the loss of

lives is an everyday occurrence. The approach outlined in the preceding section should suggest new ways of solving the rescue problem associated with high-rise buildings. A fire in a high-rise building poses a special and critical hazard to the life and safety of the occupants. Present-day elevators are ineffective as escape routes, and stairways are poorly designed and require long times to effect rescue. In addition, these two modes of rescue are often compromised by various security practices or by fire fighters.

Therefore, it seems that a potential for improved fire safety in high-rise buildings may hinge around providing safe areas of refuge prior to total evacuation. Evacuation up to the roof level of the building, as well as to ground level with thermally protected elevators and shafts would seem to provide a substantial improvement in fire safety. To this end, NASA is considering a program to determine the feasibility of applying NASA-developed fire-retardant materials and technology to provide refuge areas and escape routes in high-rise buildings. The study will concentrate on the requirements for protection of occupants caught in a fire in a high-rise structure and will include the concepts of providing detection, refuge chambers, special escape routes that minimize the fire hazard, elevator car and shaft protection, dangers of exposure to smoke and toxic gases, emergency medical needs, life support systems, and communications with the outside (refs. 42 - 44).

Fire detection in dwellings is of critical importance if the property loss is to be minimized and the lives of the occupants are not to be placed in jeopardy. Occupants or passersby detect most dwelling fires. The other basic form of detection is automatic detection by mechanical, electrical, or chemical devices. While the presence of people in the buildings increases the chances of early detection and prompt corrective actions, the sense of man alone cannot be relied upon to provide adequate surveillance without automatic instrumentation. Strategically placed automatic detectors are the most effective means of detecting a fire in the incipient or smoldering stages before rapid development takes place. There must be connected to a positive alarm system an automatic deluge system for maximum effectiveness.

CONCLUSIONS

This report has briefly reviewed the NASA developed fire retardant technology for possible protection of dwellings from fire.

The general conclusion is that fire retardant materials developed for space use are too expensive and therefore of limited value for wide use in dwellings at the present time.

The toxicity hazard needs more attention before widespread application of these materials can be undertaken.

One promising application appears to be the protection of elevator cars and shafts and the provision of refuge areas in high-rise buildings where cost impact is minimized.

Other areas where materials can be utilized at premium cost are steel beams, partitions for attached garages, and paneling in high risk areas.

Ames Research Center
National Aeronautics and Space Administration
Moffett Field, Calif. 94035, April 4, 1973

REFERENCES

1. Harmaltry, T. Z.: Ten Rules of Fire Endurance Rating, National Research Council, Ottawa, Canada, Building Research Note no. 46, July 1964.

2. Heylin, Michael: Plastics in Construction, Chemical & Engineering News, vol. 49, no. 13, pp. 16-20, March 29, 1971.

3. Craig, Jerry W.: Apollo Spacecraft Nonmetallic Materials Applications. NASA SP-5096, 1971, pp. 129-135.

4. Dawn, Frederic S.: Nonmetallic-Materials Development for Spacecraft Applications. NASA SP-5096, 1971, pp. 57-63.

5. Downs, W. R.: The Combustion Process. NASA SP-5096, 1971, pp. 3-8.

6. Katsikas, C. J.; Levine, J. H.: Manned Spacecraft Nonmetallic-Materials Flammability Selection Criteria and Requirements. NASA SP-5096, 1971, pp. 9-22.

7. Kline, Harry F.: Development of Nonflammable Potting Compounds. NASA SP-5096, 1971, pp. 83-90.

8. Naimer, Jack: Apollo Applications of Beta Fiber Glass. NASA SP-5096, 1971, pp. 141-144.

9. Radnofsky, Matthew I.: New Materials for Manned Spacecraft, Aircraft and Other Applications. NASA SP-5096, 1971, pp. 91-102.

10. Neel, C. B.; Parker, J. A.; and Fish, R. H.: Heat Shields for Aircraft – A New Concept to Save Lives in Crash Fires. Astronaut. Aeron., vol. 9, Nov. 1971, pp. 18-26.

11. Davis, T. R.; Hafcher, C. W.; and Schaab, C. K.: Encapsulation of Halogen Containing Compounds. NASA CR-73374, 1969.

12. McHale, E. T.: Survey of Vapor Phase Chemical Agents for Combustion Suppression. NASA CR-73263, 1968.

13. Einhorn, I. N.; Seader, J. D.; Mihlfeith, C. M.; and Drake, W. O.: Flammability and Toxicological Characteristics of Isocyanurate Foams, Intumescent Coatings and Fluorel. Rept. UTEC–MSE–71–039, University of Utah Center for Flammability Research, March 1971, NASA Contract NAS2–6063.

14. Dufour, R. E.: Survey of Available Information on the Toxicity of the Combustion and Thermal Decomposition Products of Certain Building Materials Under Fire Conditions. Res. Bul. 53, Underwriters' Laboratories, Inc., July 1963.

15. Epstein, G.; and Hercklen, J.: Relative Toxicity of Selected Polymeric Materials Due to Thermal Degradation. Air Force Report SAMSO-TR-70-115, Dec. 1969.

16. Harris, Elliott S.: Toxicology of Spâcecraft Materials. NASA SP-5096, 1971, pp. 207-210.

17. Rudloff, W. K.: Kinds and Amounts of Decomposition Products in the Thermal Degradation of Spacecraft Materials. Rep. IITRI-71-139 CX, IIT Research Institute, Project C6221 for NASA Manned Spacecraft Center, June 1971.

18. Young, W.; and Parker, J. A.: Effect of Foams on Acetylcholinestease – Activity and Some Counter Measures. Paper presented at Third Toxicology Conference, Oct. 25-27, 1972.

19. Paciorek, K. L.; Kratzer, R. H.; and Kaufman, J.: Fundamental Ignition Study for Material Fire Safety Improvement. NASA CR-114402, 1971.

20. Paciorek, K. L.; and Zung, L. B.: Fundamental Ignition Study for Material Fire Safety Improvement. NASA CR-114357, 1970.

21. Schulman, S.; and Stanton, R. M.: Nonflammable PBI Fabrics for Prototype Air Force Flight Suits. Rep. AFML TR-70-178, Nov. 1970.

22. Parker, J. A.; Riccitiello, S. R.; Gilwee, W. J.; and Fish, R. H.: Development of Polyurethane for Controlling Fuel Fires in Aircraft Structures. SAMPE, J., vol. 5, no. 3, 1969, pp. 41-47.

23. Riccitiello, S. R.; Fish, R. H.; Parker, J. A.; and Gustafson, E. J.: Development and Evaluation of Modified Polyisocyanurate Foams for Low Heating Rate Thermal Protection. J. Cellular Plastics, vol. 7, pp. 3-8, April 1971.

24. Parker, J. A.; Fohlen, G. M.; Sawko, P. M.; and Griffin, R. N.: The Use of a Salt of p-Nitro-Aniline as a Component for Intumescent Coating. SAMPE, J., vol. 4, no. 5, 1968.

25. Riccitiello, S. R.; Fohlen, G. M.; and Parker, J. A.: Thermal Reactions of N, N'Bis (p-nitrophenyl) Sulfamide and p-Benzoquinone Dioxime-Acid Mixtures, J. of Appl. Polymer Sci., Part A-1, vol. 9, Feb. 1971, pp. 317-323.

26. Poshkus, A. C.; and Parker, J. A.: Studies on Nitroaniline-Sulfuric Acid Compositions Aphrogenic Pyrostats. J. of Appl. Polymer Sci., vol. 14, 1970, pp. 2049-2064.

27. Pope, R. B.; Riccitiello, S. R.; Goldstein, H. E.; and Parker, J. A.: Ablative Thermal Protection at Low Heating Rates. SAMPE Proc., vol. 15, 1969, pp. 421-424.

28. Sawko, P. M.; Fontes, E. J.; and Riccitiello, S. R.: An Intumescent Coating for Improved Fuel Fire Protection of Heat Sensitive Articles. J. Paint Technology, vol. 44, no. 571, August 1972, pp. 51-55.

29. Fohlen, G. M.; Parker, J. A.; Riccitiello, S. R.; and Sawko, P. M.: Intumescence: An In Situ Approach to Thermal Protection. NASA SP-5096, 1971, pp. 111-119.

30. Warren, Paul C.: How Plastics Burn. SPE Journal, vol. 27, no. 2, Feb. 1971, pp. 17-22.

31. Tewarson, A.: Some Observations on Experimental Fires in Enclosures. July 1971, Rept. FMRC-18305, PHS-5R01 EC 00355-02, HEW Grant Factory Mutual Research Corporation.

32. Loftus, J. J.; Gross, D.; and Robertson, A. F.: A Method for Measuring the Heat Release of Materials in Building Fires, Am. Soc. Testing Materials Proc. 61, pp. 1336-1348.

33. Primeaux, Gary: Component Flammability Testing. NASA SP-5096, 1971, pp. 4 (1-12).

34. Gross, D.; Loftus, J. J.; and von Robertson, A.F.: Method for Measuring Smoke. Special Tech. Pub. no. 422, ASTM, 1967, p. 190.

35. Waterman, T. E.: Determination of Fire Conditions Supporting Room Flashover. DASA Report 1886, IIT Research Institute Project M6131 for Defense Atomic Support Agency, Sept. 1966.

36. Waterman, T. E.: An Investigation to Evaluate Cellular Plastics From Fire Performance Standpoint. Final Report, IIT Research Institute Project J8116 for Society of the Plastic Industry, Nov. 1969.

37. Waterman, T. E.: Effects of Material Location and Area Coverage on Flame Spread in Corridors. IIT Research Institute Project J8072 for Society of the Plastics Industry, Jan. 1970.

38. Waterman, T. E.: Relation of Building Occupancy and Design to Use of Combustible Materials of Construction. IIT Research Institute Rep. for Society of the Plastics Industry Inc., Oct. 1968.

39. Waterman, T. E.: Scaling of Fire Conditions Supporting Room Flashover. DASA Report 2031, IIT Research Institute Project M6170 for Defense Atomic Support Agency, Dec. 1967.

40. Waterman, T. E.: Smoke Produced by Exterior Insulated Wall Systems. IIT Research Institute Special Report for Society of the Plastics Industry, Inc., Nov. 1968.

41. Waterman, T. E.: The Ability of Existing Small Scale Tests to Predict Smoke Production of Interior Finish Materials in Large Fires. IIT Research Institute Project J8072 for Society of the Plastics Industry, Oct. 1969.

42. Galbreath, M.: A Survey of Exit Facilities in High Office Buildings. Building Research Note no. 64, National Research Council, Ottawa, Canada, Oct. 1968.

43. Galbreath, M.: Time of Evacuation by Stairs in High Buildings. Fire Research Note no. 8, Fire Fighting in Canada, Feb. 1969.

44. Galbreath, M.; and Shorter, G. W.: Air Pressures Contribute to a Smoke-Free Corridor. Fire Research Note no. 3, Fire Fighting in Canada, Dec. 1965.

C-47 AIRCRAFT FUSELAGE

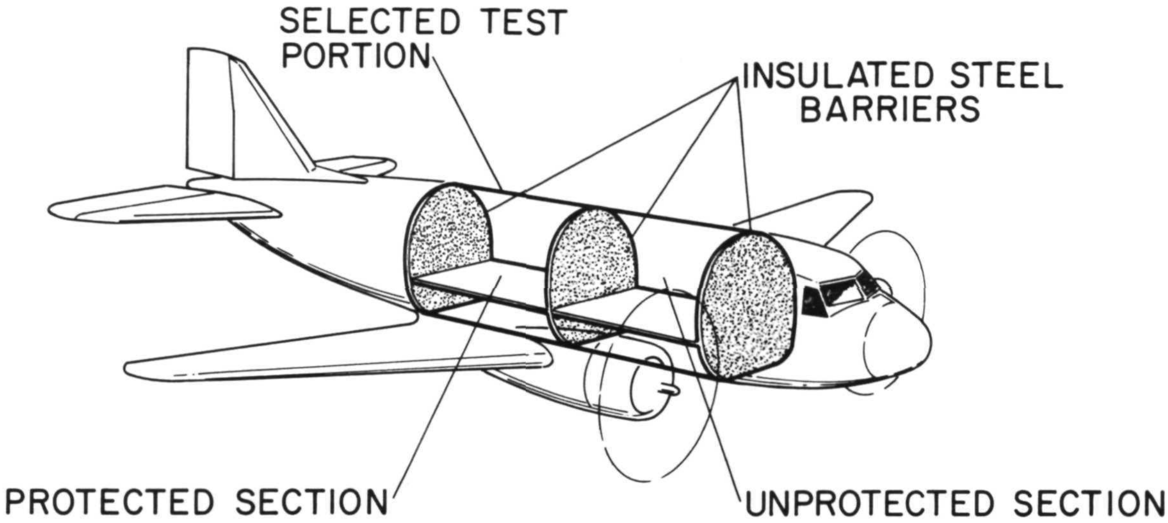

Figure 1.– Portion of aircraft used for test.

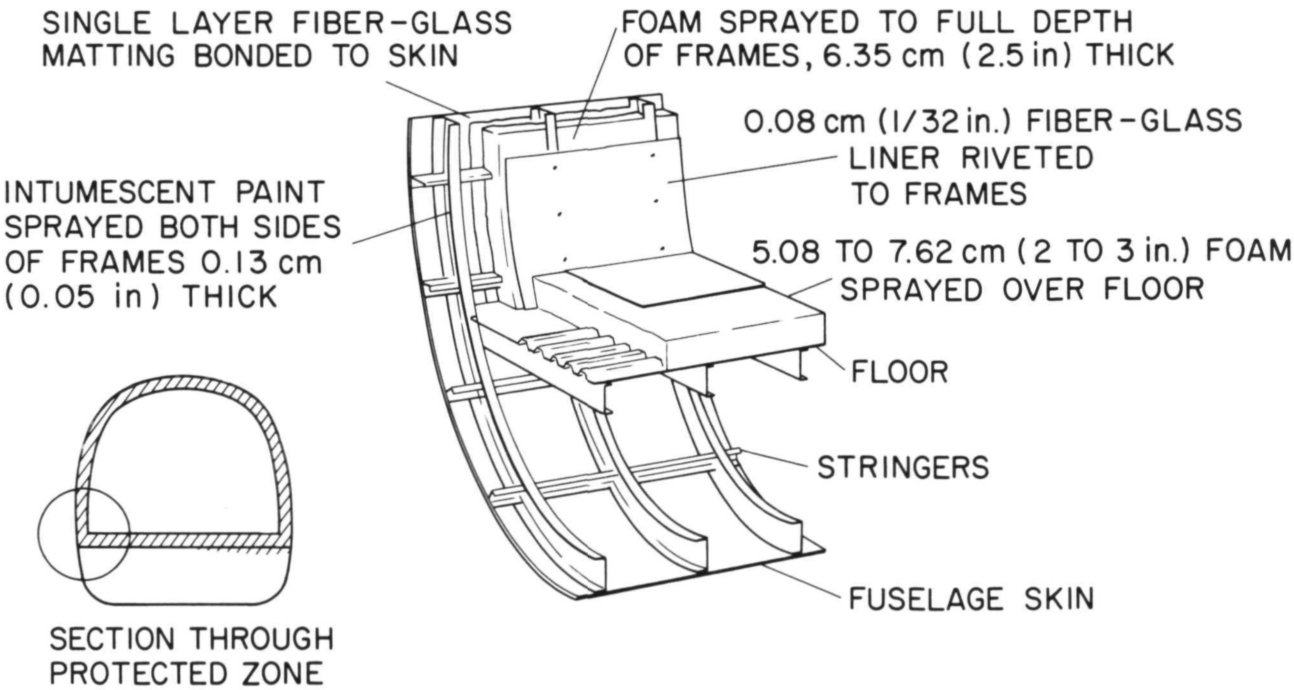

Figure 2.– Installation of fire-protection materials.

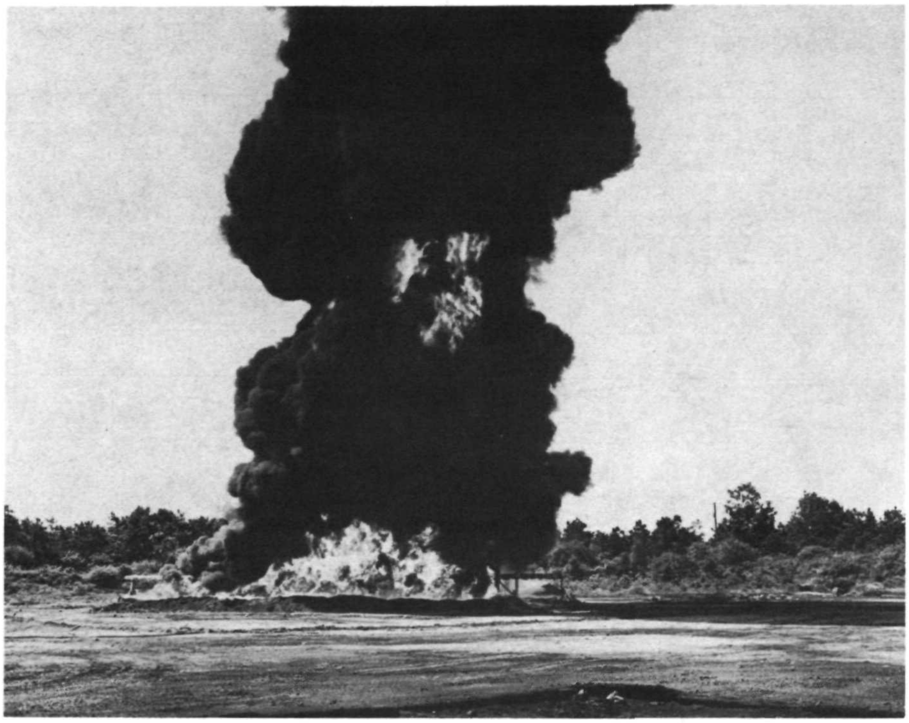

Figure 3.– Fire at maximum development during test.

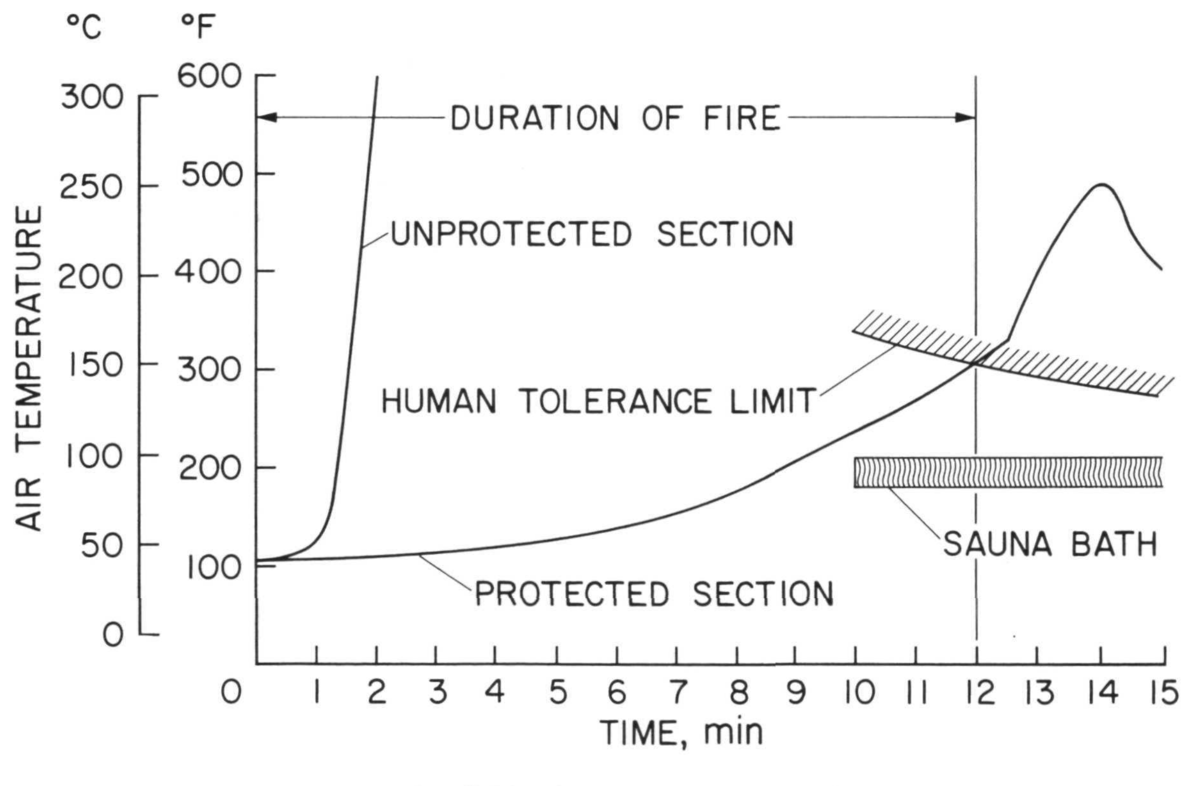

Figure 4.– Cabin-air temperature during fire.

NASA-Langley, 1973 —— 18 A-4874

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